Fostering the Creative Attitude with Remote Lab Learning Environments

An Essay on the Spirit of Research in Engineering Education

http://dx.doi.org/10.3991/ijoe.v9iS5.2750

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***Abstract*—Creativity has been proclaimed to be one of the most important 21st century skills. Facing tremendous problems, creativity and innovation were seen as key factors of a knowledge-based society able to cope with ongoing and future problems. As Engineers are addressed to play an important role in facing these challenges, the question arises in which way universities could contribute to educate creative engineers. This slightly provoking essay inducts possible boundary conditions and constraints of fostering creativity in engineering education. Moreover, it presents first results from a small-sample pre-study on higher engineering education curricula, conducted in the funded German project "ELLI–Excellent Teaching and Learning in Engineering Education", which suggests a lack of creativity education in the examined curricula. Furthermore, a descriptive analysis of the didactic approach of the finished EU-project "PeTEX–Platform for E-Learning and Telemetric Experimentation" provides information about possibilities of fostering the creative attitude in engineering education by means of remote labs. Finally, the essay resumes with future tasks for the ELLI project and open questions addressing relevant future educational and socio-economic impacts, regarding the role of creativity in engineering education and the professionalization of engineers.**

***Index Terms*—fostering creativity in higher engineering education, higher engineering education research, remote labs, creativity supporting learning scenarios, curriculum development**

I. INTRODUCTION

Creativity has been proclaimed as one of the key 21st century skills and as a driving force of economic development. With the so-called creative class, comprising different types of creative workers, tackling complex societal problems ranging from solving economic problems through creating innovative technological solutions to devising new ways of social entrepreneurship, the role of creativity will increase dramatically in the years to come. Already today, many of the fastest-growing jobs and emerging industries rely on workers' creative capacity such as the ability to think unconventionally, inventing new scenarios and producing novel solutions.

To face these demands both engineering education and professional engineering fields have to design and embrace new ways of fostering creativity of engineering students and workers. This raises three paradigmatic questions:

- What means / is creativity in the context of higher engineering education and is there a lack of creativity-fostering education in engineering curricula?
- What is creativity especially in engineering and how could engineering educators foster a "creative attitude" [1] in their engineering courses?
- Could high-end remote and virtual labs, as presented in [2] and [3], be powerful instruments for the development of a creative attitude?
- Trying to get first answers to these questions, the essay presents a few possibly slightly provoking findings and estimations of a first curriculum survey as pre-study, conducted during the first stage of the nationally funded ELLI project.
- Furthermore, the paper discusses the remote lab approach of the finished EU-project "PeTEX–Platform for E-Learning and Telemetric Experimentation" as one successful practice example on fostering creativity.

A. *What is the Creative Atitude?*

Creativity itself can be defined as the interaction among aptitude, process and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context. Creativity generates outcomes that are novel, high-quality and appropriate to the task at hand or some redefinition of that task [4], [5], [6], [7].

According to [1] "creativity and progress depend upon asking the right questions at the right time". Ref. [8] states that "being creative always requires some amount of deviating from the norm". Moreover, [9] stresses that the function of creativity is twofold: "from the societal viewpoint, the task of creativity is improvement; from the individual viewpoint, the task of creativity is expression". These two perspectives of creativity—improvement and expression—were not extremes of one aspect, they should rather be regarded as singular levels of investigation. "Individual and society interact over time to bring new ideas, products, and solutions into the realm of culture" [9].

Well, what is the creative attitude? Reference [1] defines the creative attitude as "…the desire to go against the mainstream. But such desires are stopped by parents, in school, at work—nearly everywhere [needless to say: in higher education institutions too; CT&TH]. The creative attitude entails posing one's own questions, not answering the questions of others, and it is not always easy to get away with such a point of view".

B. The Role of Creativity in Engineering

In 2004, *The National Academy of Engineering* defined the impact of creativity on engineering in the following way: "Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance. (…) Engineering is a profoundly creative process. A most elegant description is that engineering is about design under constraint. The engineer designs devices, components, subsystems, and systems and, to create a successful design, in the sense that it leads directly or indirectly to an improvement in our quality of life, must work within the constraints provided by technical, economic, business, political, social, and ethical issues" [10]. According to [11] engineers shall be able to "demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving".

C. Creativity and Teaching Engineering

"Although the idea of creativity is attractive to educators, there is a pitfall as well as a promise. From the perspective of educators, creativity is often viewed not as an end, but as a means towards ends such as improving problem-solving ability, engendering motivation, and developing self-regulatory abilities" [12]. Reference [12] proposes three basic aspects of creativity that researchers see as generally comprising the overlap between creativity and education: Respectively, they are

- the use of **creativity** (or insight**) to solve problems** in other subject areas
- **creative ideas for teaching,** and
- teaching for or attempting to **enhance the creativity of learners**

In contrary to that, [13] nominates some teachers' inherent factors that hinder the expression of students' creativity:

- **teachers' prior experiences** during their own school and university years; reproduction of these practices across time, place, person
- prevalence of **teacher-dominated convergent teaching** approaches; personal need for order
- teachers' **need to stick to the plan**; place on the acquisition of facts
- teachers' view that **unexpected student ideas are disruptive**; even soon-to-be teachers generally **prefer expected ideas** over unexpected or unique ideas
- **wrong beliefs**, behaviors and assumptions **about students' motivation** and the role of creativity in the classroom
- **scripted curricula** represent the most extreme form of convergent teaching, separating learning from the development of creative thinking
- **teaching to the test** and increased use of externally mandated, fact-based tests

Teaching to the test points students aware of what is really valued and important: "…the kind of examinations we give really set the objectives for the students, no matter what objectives we may have stated" [14]. "Regardless of how teachers encourage their students to share their creativity, unless teachers also include expectations for creativity in their assignments and assessments, then the message is clear: Creativity really doesn't matter" [13].

Reference [13] resumes that "encouraging creative thinking while learning not only enlivens what is learned but can also deepen student understanding. This is because, in order for students to develop an understanding of what they are learning, they need (…) to come up with their own unique examples, uses, and applications of that information. In order for this to happen, expectations for novel, yet appropriate applications of learning need to be included in classroom assessments of student learning".

D. Fostering the Creative Attitude in Higher Engineering Education

Regarding creativity in the field of engineering education, some work has already been done: e.g. [15] presents the creative platform, a concept that focuses on confidence, concentration, motivation and diversified knowledge. But a concrete didactic scenario for engineering education is missing. Such a scenario is delivered e.g. by [16], and [17], combining principles of enhancing creativity with problem-based learning and project-based learning in engineering education.

The research project "ELLI–Excellent Teaching and Learning in Engineering Education", funded by the German Ministry of Research and Education between 2011 and 2016, and its sub-project "KELLI–fostering creativity in engineering education" follows a different strategy to foster and evaluate creativity.

II. KELLI – FOSTERING CREATIVITY IN HIGHER ENGINEERING EDUCATION"

The sub-project "KELLI–fostering creativity in engineering education" is based on results and outcomes of the already finished German research project "Da Vinci – fostering creativity in higher education". A model of six distinctive facets to define creativity in higher education had been worked out with a comprehensive qualitative approach based on "Grounded Theory" [18], which will be presented in the next paragraph.

These six facets can be deployed to analyze given, as well as to define and stimulate new learning objectives and learning activities.

A. Learning Objectives to Foster Creativity in Higher Education

The results of the Da Vinci project show that creativity in higher education (across all disciplines) consists of six different facets [19],[20],[21],[22] (see Fig. 1).

*1) **Developing self-reflective learning skills***

Learners break out of their receptive habitus and start to question any information given by the teacher. An internal dialogue takes place and knowledge becomes "constructed" rather than "adopted".

*2) **Developing independent learning skills***

Teachers stop to determine the way students learn. Instead, students start e.g. to search for relevant literature on their own, to make their own decisions about structuring a text or even to find their own research questions and to choose adequate methods for answering them.

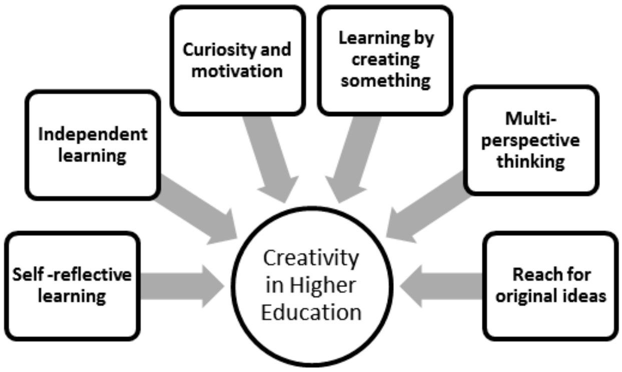

Figure 1. 6 facets of creativity in higher education

*3) **Enhancing curiosity and motivation***

This aspect relates to all measures that contribute to increased motivation, for instance the linking of a theoretical question to a practical example or presenting.

*4) **Learning by doing***

Students learn by creating a sort of "product". Depending on the discipline, this might be a presentation, an interview, a questionnaire, a machine, a website, a computer program or similar. Students act like "real" researchers.

*5) **Evolving multi-perspective thinking***

Learners overcome the thinking within the limits of their disciplines or prejudiced thinking. They learn to look automatically from different points of view on an issue and use thinking methods which prevent their brain from being "structurally lazy" [23].

*6) **Reaching for original ideas***

Learners aim to get original, new ideas and prepare themselves to be as ready-to-receive as possible. Getting original ideas cannot be forced, but by the use of appropriate creative techniques and by creating a suitable environment (allowing to make mistakes and to express unconventional ideas without being laughed down or rejected) the reception of original ideas can be fostered.

In the following paragraph these six facets will be used to question the objectives and activities defined in a small sample of engineering curricula.

B. Analysis of Module Descriptions

In the KELLI subproject, the module descriptions of six engineering education curricula (Manufacturing Engineering and Electrical and Electronic Engineering IT) of three German universities (RWTH Aachen University, Ruhr University Bochum, TU Dortmund University) were analyzed against this background in a first analytical pre-study in order to get to know which aspects of creativity are fostered.

C. Results and Discussion

As a result, the creativity-aspects 1 (self-reflective thinking), 3 (curiosity and motivation), and 4 (learning by doing) are highly developed in both courses of all three universities. Apart from one exception these aspects exhibit shares of over 50%. On the other hand, the aspects 2 (independent learning), 5 (multi-perspective thinking) and 6 (reach for original ideas) can be found only in small proportions at percentages below 50%, in aspects 5 and 6 even below 10%, apart from another exception. (see Fig. 2).

To sum up, the pre-analysis of the module descriptions indicates that students were encouraged to think critically and self-reflective in the selected courses. They had to demonstrate levels of motivation and commitment in their courses and were trained to "create" something and to work practically. However, independence, collaborative development of ideas and the exchange with other disciplines for open-minded discussions, scenarios and experiments, were almost not required or promoted. What emerges is a picture of diligent students who rather work conscientiously on given tasks than on finding new problems, questions and solutions on their own and in discussion with others. The fact that in some of the courses students are not free to pick the topic of their thesis adds to this picture: they can only select from a predefined pool of research questions developed by their respective teachers. In this way many learning tasks may hinder creative cognitive processes relating to research, such as:

- detection of relevant research questions
- deliberation whether an issue is workable
- creation of a feasible research plan, or
- assessment and implementation of eligible methods

Due to this, students are neither encouraged to develop a "bigger picture" of their discipline, nor to build up a "spirit of research" [24], [25], [26] as for instance:

- (collaborative) reasoning about current scientific issues in the community
- setting up and discussing new (and sometimes rather risky) theories
- own decision making and seeking collegial advice

If students were to see the "bigger picture", they might get an impression about the value and importance of their work as well as its location and interrelationship in the domain.

Through the findings of this pre-study the question arises whether the current understanding of fostering creativity in engineering education is appropriate.

Moreover, students seem to have a different understanding of creativity. An interdisciplinary survey (n=320) at TU Dortmund University) shows that students regard "openness", "freedom", "stimulation", "inspiration" and "empowerment" as factors that promote their creativity.

These results of the finished pre-study need to be treated cautiously since they depend on a rather small, arbitrary sample of only six courses from three different universities. Further qualitative and quantitative research will be done.

D. Practice Example: Fostering the Creative Attitude in Higher Engineering Education with a Remote Lab Approach

Just a few years ago reference [27] stated on the basis of a literature review that "hands-on lab adherents emphasize the acquisition of design skills as an important educational goal, while remote laboratory adherents do not evaluate their own technology with respect to this objective". Ref. [27] defines design skills as the "ability to design and investigate [which] increases student's ability to solve open-ended problems through the design and construction of new artifacts or processes". This raises the question whether high end remote and virtual labs, as pre-

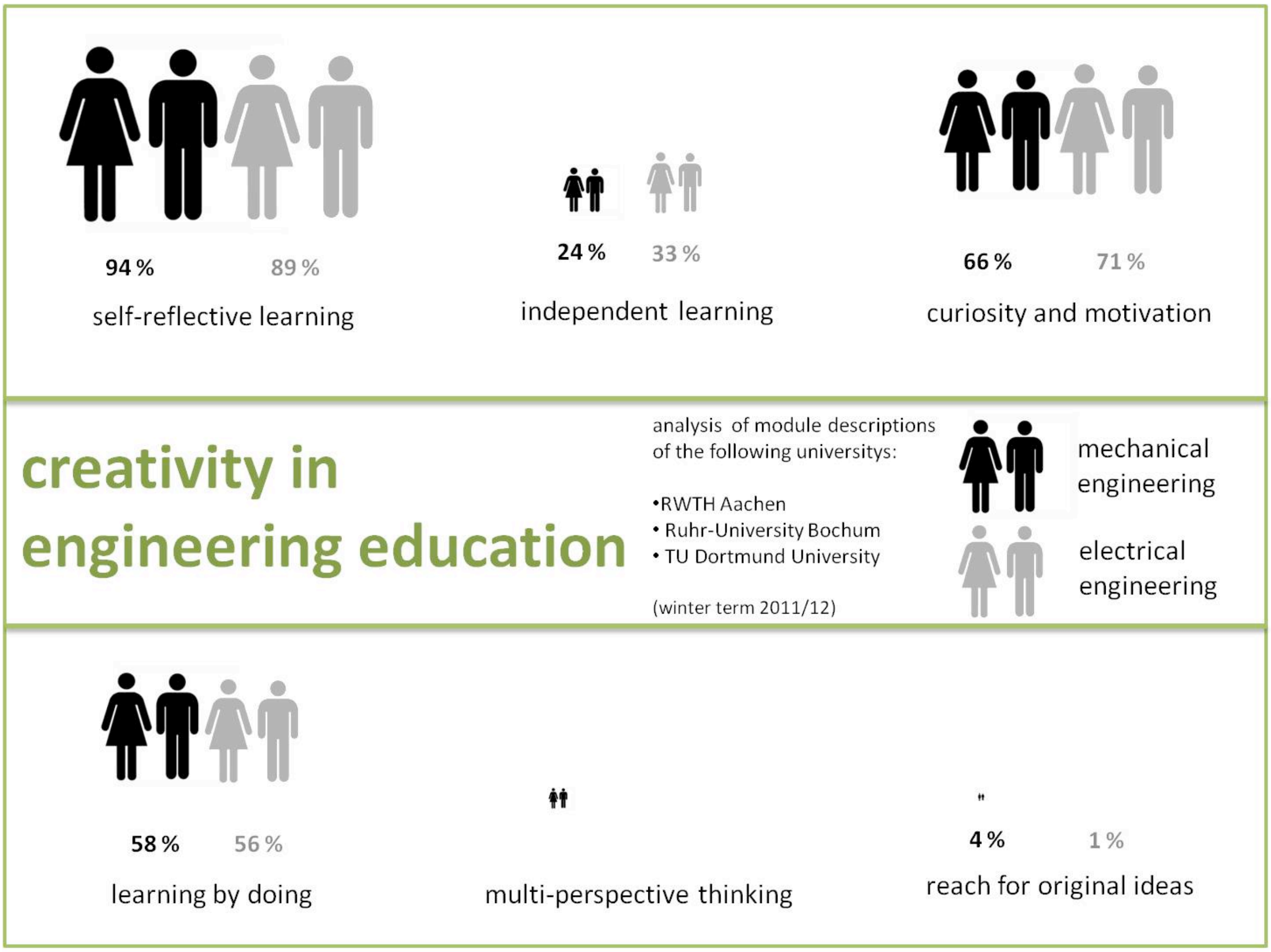

Figure 2. creativity in engineering education

sented in [2] and [3] can be powerful means to foster the creative attitude, and how this could be achieved.

The didactical concept of the "Platform for E-Learning and Telemetric Experimentation—PeTEX" (see Fig. 3) is one example [28],[29]. The PeTEX system is intended for application in higher education [30], [31] and for workplace learning [32], [33].

The PeTEX system combines a tele-operated experimentation platform (material testing, particularly forming, cutting and joining) with a collaborative learning environment based on Moodle [34],[35]. Established on "experiential learning" [36],[37],[38] it provides three different learning levels by deploying three didactic approaches and addressing three problem types [39],[40]. The learning levels correspond to the aforementioned six facets of fostering creativity (see table 1).

1) Three Consecutive Problem Levels to Foster Different Facets of Creativity

a) Beginner Level: Learning with Interpolation Problems

Students in the beginner-level are guided through the learning platform. They are asked to create predefined and expected orders in a given complexity of elements and actions by identifying, assembling and executing all given elements and actions in the right order to solve the task. On the first PeTEX learning level, this is to conduct predefined experiments correctly which comprise interpola

TABLE I.
THREE CONSECUTIVE LEARNING LEVELS, CORRESPONDING TO THE PROBLEM TYPES AND THE SIX FACETS OF CREATIVITY

Learning Levels	Didactic approach	Problem type	Creativity facet
1. level: Beginner	scripted learning paths	interpolation problems	1. self-reflective learning 2. independent learning skills
2. level: Intermediate	real world scenarios	synthesis problems	3. curiosity and motivation 4. learning by creating something
3. level: Advanced	research-based learning	dialectic problems	5. multi-perspective thinking 6. reach for original ideas

tion problems. According to [41],[42],[43] interpolation problems consist of three elements:

1. a predefined starting point
2. a concrete terminal point
3. a concrete and predefined solution process how to bridge the gap between starting point and terminal point

The challenge of this kind of problem is to correctly fulfill a sufficiently complex task according to the given and scripted path. It deals with recognition of and acting in complexity, e.g. understanding the manual, identifying the relevant units of the real equipment introduced in the manual. The next step is to combine, assemble and connect these elements in the right scripted technical and logical order to fulfill the predefined task as well as to produce the expected results.

The main creativity facets addressed by this kind of task are to break out of the receptive habitus, to create and internalize psycho-motoric operation chains, to gain first experience of basic principles and to start questioning the given information by transforming them into correct action (see facet 1: self-reflective learning).

Moreover, students at the beginner level have the option of repeating the given experiments over and over as long as necessary to pervade the related learning activities. In a further step, students can vary the input data settings to generate a deeper understanding of the underlying process models.

Furthermore, the absence of time and space restrictions in web-based learning facilities allows the students to experiment from almost everywhere at any time. Combined with unconditional repetition and variation of "walk-throughs" [44], learning will be substantiated and enhanced gradually by self-directed "playing" which is usually not offered in common laboratory work settings. This strengthens the students' capabilities for learning in a self-determined manner (see facet 2: independent learning).

b) Intermediate Level: Learning with Synthesis Problems

At the intermediate level, learners have to apply and transfer their gained knowledge for solving given real-world cases and scenarios. According to [41],[42],[43] real world scenarios relate to synthesis problems which consist of three elements:

1. a predefined starting point
2. a concrete terminal state
3. lack of a defined solution process to bridge the gap

The challenge of this problem type is to find, to develop and to deploy a sufficient solution path to a given problem consisting of a presented starting point and an expected terminal point by applying divergent and convergent thinking to find an appropriate solution.

Rewarding and effective problem solving is seen as one main success factor to increase self-efficacy and to intensify interest and enthusiasm [45], [46], [47] (see facet 3: curiosity and motivation).

The creative final product is the developed solution gained in iterative loops and mostly "by doing" (see facet 4: learning by doing).

c) Advanced Level: Learning with Dialectical Problems

Learners at the advanced level have to design own research questions and to develop appropriate experiments. According to [41],[42],[43] dialectical problems consist of

1. no predefined starting point
2. no predefined terminal point
3. no predefined solution process

The challenge for learners is to apply developed knowledge, skills and competencies in order to find and define novel and origin problems as research questions, defining a starting point, a final state, and the means for gaining it.

The underlying creative processes can be triggered, animated and intensified by applying changes of perspective. The integration and negotiation among related objectives, views, intentions or theoretical positions, which are involved by the chosen perspectives, may lead to novel scientific questions and more holistic and sustainable solutions for engineering problems. Hence, it is up to the researcher to determine the degree of interdisciplinarity, ranging from different engineering disciplines to the integration of e.g. the humanities, psychology and education, environmental sciences, or liberal arts, considering e.g. participatory design, technology assessment, engineering results assessment, involvement of stake holders and target groups [48],[49], environmental issues, or ethical issues, (see facet 5: multiperspective thinking).

The intended outcome of the advanced level is something like a tangible new product, a prototype, a theory, a process (see facet 6: reach for original ideas).

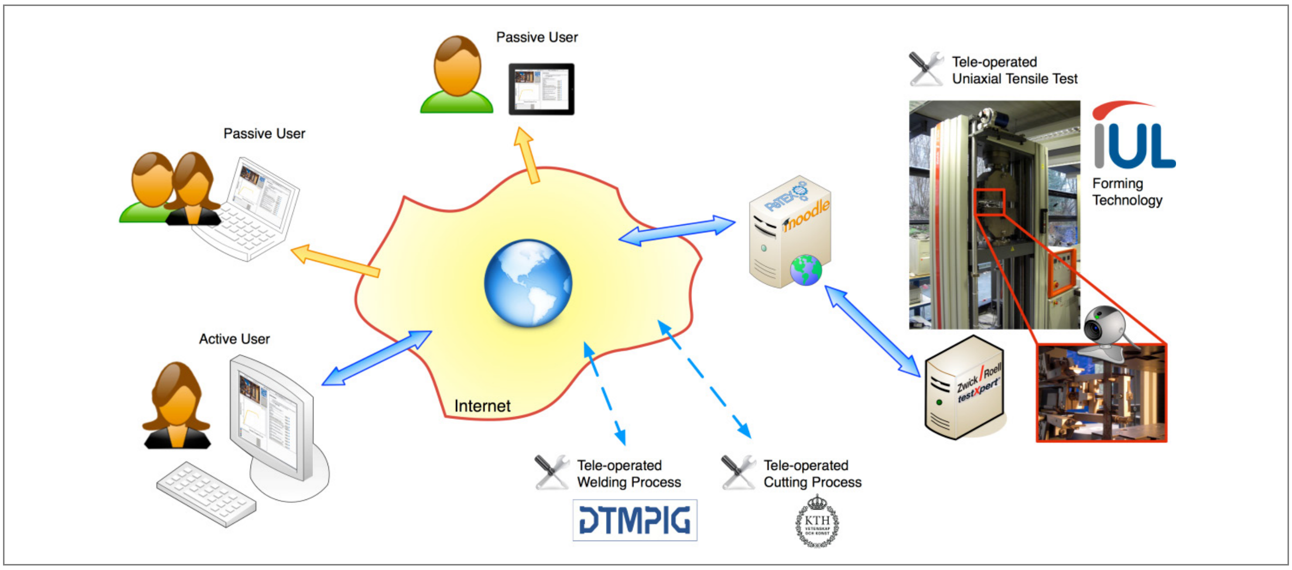

Figure 3. The PeTEX principle [34]

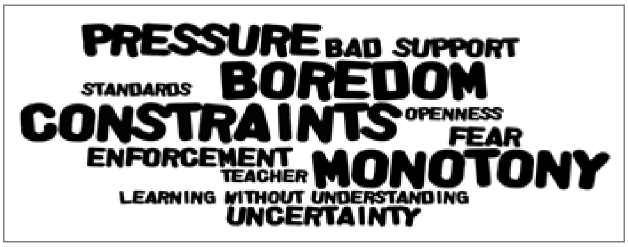

Figure 4. Students' perspective on factors that hinder creativity

Figure 5. Students' perspective of factors that foster creativity

2) Dealing with Increasing Complexity in PeTEX for Fostering "The Spirit of Research"

The more the students work with PeTEX, the more freedom they receive to define their own research problems and to find the answers on their own. Furthermore, PeTEX provides collaboration, not only with other students (from other universities and even other countries), but also with lifelong learners. In summary, PeTEX offers an important contribution to foster the "spirit of research" by providing gradually more "openness", "freedom", "stimulation", "inspiration" and "empowerment" to the students; factors which promote their creativity (see Fig. 4 and Fig. 5).

III. CONCLUSIONS

The essay posed two main questions: What means / is creativity in the context of higher engineering education and is there a lack of creativity fostering education in engineering curricula? To answer these questions the essay presented results of a first curriculum survey as pre-study, conducted during the first stage of the nationally funded ELLI project.

The pre-study confirms an absence of fostering research spirit in the chosen sample of engineering education curricula. Since the results of the pre-study depend on a rather small, arbitrary sample, further qualitative and quantitative research will be undertaken.

Furthermore, the paper discussed the remote lab approach of the finished EU-project "PeTEX–Platform for E-Learning and Telemetric Experimentation" as one successful practice example on fostering creativity.

IV. FUTURE WORK IN ELLI

- Extension of the remote laboratory equipment
- Formative evaluation of creativity fostering teaching and learning practices
- Expansion of the module description analysis with emphasis on creativity
- Implementation of more interviews among university teachers in HEE and employers
- Revision and improvement of the six facets model according to HEE
- "Through the barricades" and "rage against the machine" – HEE workshops for faculty and staff on fostering creativity
- "LabDid 2.0" – HEE workshop on lab didactics for faculty and staff

V. CHALLENGING OPEN QUESTIONS

This contribution resumes with open questions addressing relevant future educational and socio-economic impacts. It remains unclear whether these points also play an important role in the perspective of teachers and, furthermore, parts of the society:

- What wishes and visions do teachers, researchers, industry representatives, professional association representatives have with regard to the education of tomorrow's engineers, their creativity and research spirit?
- Are open experimentation and trying out new ideas, is the search for the unknown new truly important for a society in a globalized world economy?
- Does our economic society indeed need diligent professionals who execute given tasks instead of developing their own initiatives?
- What kind of education will be needed if a society wants to bring up future inventors who are able to cope with challenging future problems?
- How could teachers be trained efficiently and successfully in creativity fostering techniques?
- How could creativity and interdisciplinary knowledge in engineering education courses and curricula be fostered?

These questions should be discussed in a broad social—multidisciplinary—debate and further studies on the impact of teaching creativity in engineering education need to be done.

ACKNOWLEDGMENT

The authors sincerely thank: Christian Pleul, Prof Dr.-Ing A. Erman Tekkaya, Dr.-Ing. habil. S. Chatti, Prof. Dr. Dr. J. Wildt, Dominik May, (TU Dortmund University), Prof. F. Micari, Prof. E. Lo Valvo, Prof. L. Fratini, PhD R. Licari, PhD G. Buffa (University of Palermo, Italy), Prof. M. Nicolescu, P. Johansson (KTH–Kungliga Tekniska Högskolan, Stockholm, Sweden) for their great cooperation during the PeTEX project.

Last but not least the authors sincerely thank Prof. Dr.-Ing. Thorsten Jungmann (FOM Hochschule Düsseldorf), Emanuel Bielski (TU Dortmund University) and all friends and colleagues at TeachING-LearnING.EU—the first subject center for engineering education in Germany—for many inspiring discussions and the productive view exchange.

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This article is an extended and modified version of a paper presented at the EDUCON2013 conference held at Technische Universität Berlin, Berlin, Germany from March 13-15, 2013. The authors would like to thank the German Federal Ministry of Education and Research BMBF for funding the project Da Vinci - fostering creativity in higher education, (2008-2011) and the project ELLI - excellent learning and teaching in engineering education (2011-2016) and the DLR Project Management Agency (part of the German Aerospace Center) for the implementation and support. The PeTEX project (142270-LLP-1-2008-1-DE-LEONARDO-LMP; 2008-2010) has been funded with support from the European Commission (Lifelong Learning Programme). This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein. Received 15 May 2013. Published as resubmitted by the authors 27 May 2013.